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Reply to Attn of: ED43

September 19, 1983

TO: Distribution

FROM: ED43/Dr. Hugh J. Christian

SUBJECT: Newsletter #5 on NASA's Satellite Lightning Mapper Sensor Development Activities and Associated Research

This letter is the fifth in the series of information newsletters pertaining to our lightning sensor developments and research program. The program is under sponsorship of NASA Hq Earth Sciences and Applications Division with Dr. James Dodge as the Hq Program Manager.

1. Space Based Programs

   a. Lightning Mapper Sensor Development

The lightning mapper sensor feasibility study contracts with Hughes Aircraft and TRW are nearing completion. The design guidelines established at the beginning of these studies were:

1. Spatial resolution ~ 10 x 10 km

2. Field of view - full earth disk

3. Detection efficiency - 90% of lightning events in FOV (this guideline was later quantified using U-2 data to be a minimum sensitivity threshold of 4 μJoules/m^2-sr at 8683 Å).

4. Dynamic range 10^7 to 10^{12} watts (changed to a threshold of 4.7×10^5 $\mu J/m^2 sr$)

5. False alarm rate $\lesssim$ 10% of detected flashes (this criteria requires a signal to noise ratio of approximately 6).

6. Data dissemination ~ near real time (< 5 min)

Midterm review of both studies were held at Marshall in early May. Both contractors showed good progress with the emphasis in their approaches on satisfying the scientific and application requirements for the lightning mapper with a design that utilizes present technology. While these studies are not yet complete, it appears that the guidelines, which were selected based on requirements established by user inputs, are generally obtainable. Study results include:

a. Detailed radiometric calculations that support the feasibility of detecting and locating lightning from geostationary orbit during daylight. The difficulty with this observation is that the background illumination caused by sunlight reflecting from the tops of clouds is much brighter than light intensity produced by the lightning. In order to be able to maximize the ratio of lightning signal to background signal several filtering techniques must be implemented. These include:

1. SPECTRAL FILTERING - a filter must be optimized to pass a strong lightning emission line yet be narrow enough to minimize the amount of background light transmitted.

2. TEMPORAL FILTERING - the detector integration time must be long enough to include most of the energy from a single lightning pulse yet short enough to minimize background signal.

3. SPATIAL FILTERING - the size of an individual pixel's field of view on the earth (IFOV) must be driven by the cloud top area illuminated by a typical lightning event. Making an IFOV much smaller than the illumination size will divide the lightning signal between multiple pixels and decrease the signal to noise ratio. Too large an IFOV results in underfill causing an increase in the background signal while the lightning signal remains constant. Again the signal to noise ratio declines.

b. Processing electronics at or near the focal plane will still be required after the spatial, temporal, and spectral filtering is accomplished. This is because the minimum strength lightning signal will still be significantly weaker than the remaining background signal and the data rate coming off the focal plane will be much too high to handle without compression. It is expected that this subsystem will consist of an electronic filter to remove the remaining background signal and formatting electronics to prepare the signal for transmission.

c. No commercial, off-the-shelf, solid state detector array can satisfy the lightning mapper requirements; consequently, a custom detector will have to fabricated. The main difference will be the addition of multiple, parallel output lines instead of the customary single multiplexed output line. This requirement is driven by the need to read out of the array every millisecond or so; a speed that far exceeds the capability of standard large arrays.

In summary, the studies to date suggest that an optical lightning mapper is feasible and within the present state-of-the art, that many scientific and application requirements can be satisfied, and that in-depth trade-off analyses are necessary before a set detailed design can be selected.

b. NOSL Experiment

The NOSL Experiment was flown on STS-6 and data, both photography and electronic pulses, were recorded on both a nighttime storm near the coast of South Africa and a day time storm southwest of New Orleans over the Gulf of Mexico. There were a total of eight photos of the nighttime storm that look very similiar to the photography obtained by our U-2 Thunderstorm Overflight Program cameras. A total of 19 minutes of experiment time was accomplished providing 28 pulses over a number of various storm systems. Data are currently being analyzed by the PI team under the direction of Dr. Bernie Vonnegut, SUNYA

2. U-2 Flight Program

The 1983 Spring U-2 flights were completed in June. Eight sorties were conducted between May 20 and June 5. Rapid scan satellite data from GOES-E were collected at 3-minute intervals during four of the flights (May 25, May 28, June 3 and June 6) and at 15 minute intervals for two others (May 31 and May 22). Single doppler radar volume scans were made during the U-2 flights on the aforementioned dates.

Additional storm electricity measurements were made during the U-2 flights at NSSL and with the instrumented storm chase van operated by the University of Mississippi. The storm van collected ground truth data beneath storms simultaneously with the U-2 flights. A preliminary comparison of LLP lightning ground strikes with storm chase cloud-to-ground flash electric field changes for two U-2 flight lines on June 3 yields maximum LLP detection efficiencies of 75% (nine of twelve events detected) and 81% (17 of 21 events detected) for a storm approximately 300 km from the center of NSSL's LLP network. Navigation data from the U-2 flights will be used to determine the U-2 locations above cloud top relative to the ground strike locations. These data sets are the first to be used for multiple sensor confirmation of LLP ground strikes beyond 100 km. A preliminary analysis of coincident flashes for two flight lines shows the following:

RUN #7 (0401-0414 GMT)

TYPE	U2 ΔE* STORM CHASE	U-2 WAD**	U-2 OPS***	LLP (Maximum Detection Efficiency)
Intercloud	31	16	11	-
Cloud-Ground	22	11	5	17(17/21 = 81%)
TOTAL	53	27	16	-

* E = electric field change
**WAD = wide angle optical detector
***OPS = optical pulse sensor

RUN #8 (0426-0437 GMT)

TYPE	U2 ΔE STORM CHASE	U-2 WAD	U-2 OPS	LLP (Maximum Detection Efficiency)
Intercloud	47	28	18	-
Cloud-Ground	10	6	4	9(9/12 = 75%)
TOTAL	57	34	22	

For coincident and non-coincident flashes, the WAD detected 107 flashes and the OPS detected 65 flashes out of a total 174 flashes detected by the field change meter aboard the U-2. These different optical and field change quantities are due to the optical sensors detecting events only within their fields of view (directly beneath the U-2) whereas, the field change meter has a detection range in excess of 80 km.

3. Ground Based Programs

The data concentrator for the BLM lightning network was installed at Salt Lake City and real time data access using McIDAS has been possible since the second week of June. Data for 1983 will be in the University of Wisconsin McIDAS archive. Algorithms exist to plot ground strikes onto satellite images and do lightning time series plots for individual storm cells or storm complexes.

The highest 24 hour flash total for the network was 29,000 CG flashes. The LLP lightning network at MSFC was installed in June and the data are being archived on magnetic tape.

The phase linear interferometer network collected simultaneous data of hurricanes Alicia and Barry at MSFC and Southwest Research Institute. These data are being analyzed now.

4. Research Review Summary

a. SIGNIFICANT ACCOMPLISHMENTS FOR FY-83:

*Details of accomplishments are described in individual papers; this overview presents program status and overall progress.

Of major importance are the sensor feasibility studies conducted by TRW and Hughes Aircraft. Using the U-2 lightning data to form the design criteria, they have investigated a number of innovative ideas using mosaic array detectors and focal plane processing techniques that can be optimized for the detection of lightning from space. Status reports were presented during the second week of May, and final reports are due in September.

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*Copy of NASA/MSFC FY83 Atmospheric Processes Research Review available on request.

Results from analysis of U-2 lightning data have placed the sensor development portion of the program on solid, quantitative basis. There exists sufficient lightning characterization data to proceed with prototype development for U-2 and other operations. The sensor development issues are basically technological at this stage.

Scientific applications of the lightning mapper have also been addressed and published. *In addition, a number of ongoing research projects seek to understand relationships between lightning activity and storm dynamics. Some results from these studies are presented below. The major emphasis has been to analyze lightning data in conjunction with other data sets, such as Doppler radar, GOES images, cloud top heights, updraft velocities, rainfall rates, and so on. Limitations have included the lack of lightning data over large geographical areas. This type of problem will be reduced when data from ground-based lightning networks are properly archived and made available for scientific research; however, it will not be eliminated until full disk coverage is available.

Our present lightning remote sensing systems use RF techniques. They include ground strike location networks positioned in the Western United States, along the Eastern Coast, at NSSL, etc., dual-base phase linear interferometers (San Antonio, TX, and MSFC), and a dual ELF system (NSSL and MSFC). These systems hold the potential of providing good geographical coverage for further study of lightning activity in large storm systems.

In addition to studies of mesoscale lightning activity, work has continued on fundamental lightning physics using both RF and optical techniques. Absolute spectral irradiance measurements of both cloud to ground and intercloud flashes have been made as well as estimates of total flash power.

b. FOCUS OF CURRENT RESEARCH ACTIVITIES:

The spring FY-84 U-2 field program is the major current research activity. Attempts are being made to fully coordinate the multiple sensing systems which should include the NASA U-2, NSSL atmospheric electricity sensors, dual Doppler radars, Storm Intercept (U. of Miss), RF sensors (NMIMT), phase linear interferometers (SWRI and MSFC), ELF system (NSSL and MSFC), rapid scan GOES (NOAA), an acoustic thunder array (Rice) and balloon borne electric field sensors (Rice and U. of Miss).

c. PLANS FOR FY-84:

The development of a brass board lightning mapper-type sensor will be a prime focus for FY-84. In addition, it is expected that major efforts will be expended in analyzing data

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*See the February, 1983 issue of the "Bulletin of the American Meteorological Society", Vol. 64, No.2.

acquired during the spring field program, and it is anticipated that exciting data from the BLM and East Coast networks will be available for the study of lightning activity in mesoscale storm systems.

Participation in TRIP-84 at the National Severe Storms Laboratory is in the planning stage.

5. Summary of FY-83 Research Review Report Papers:

a. Data showing absolute spectral irradiance measurements of lightning from 330 nm to 880 nm were presented. A comparison of Orville's DMSP (optical) midnight global lightning data base with the global distribution of lightning at midnight from the ISS-b satellite (radio frequency) shows good qualitative agreement. An east coast lightning ground strike network was operated from SUNYA throughout the winter of 1982 and lightning activity has been seen every week (R.E. Orville and B. Vonnegut).

b. The storm intercept program has made measurements of electric fields and lightning near mesocyclones and has collected ground truth data to support the U-2 overflights (R.T. Arnold and W.D. Rust).

c. Analyses of several positive CG (+CG) flashes have been made to determine their physical characteristics. The diurnal variation of +CG for July 1982 shows that the ratio of +CG/CG flashes peaks about 4 hours later than the peak for CG flashes of both polarities. An analysis of CG flashes in tornadic storms indicates that there is no obvious minimum in CG flash activity in the storm as a whole during the time of tornadoes. The fraction of CG flashes that lower positive charge is larger before and during the tornado, and the number of strokes per flash increases after the tornadic stage ends. Within 10 km of the mesocyclone, CG flashing rate increases as the mesocyclone weakens; pattern in +CG flashes and number of strokes remains the same. The identification of CG flashes with an omnidirectional, long-range ELF system is helping provide CG verification for +CG flashes, CG flashes beneath the U-2 and CG flashing rates in severe storms (W.D. Rust, D.R. McGorman, W. Taylor, R.T. Arnold, B. Vonnegut).

d. On STS-4 interesting 16mm sequences taken at 24 frames per second showed lightning discharges that continued to grow and spread at speeds of the order of 10^5 m/s at distances of 60 km or more. Preliminary examination of the photographic film obtained on STS-6 shows lightning photographs are less frequent and of shorter duration and smaller dimensions than those taken on STS-4. In contrast to the illuminated areas observed on STS-4, which ranged in color from yellow to deep red, the discharges on STS-6 showed various colorations in the same frame varying from red through white to blue. (B. Vonnegut, M. Brook, O.H. Vaughan, Jr.)

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